Estimating Economic Impacts of New Dimensional Control Technology Applied to Automobile Body Manufacturing*

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Abstract

CONSAD analysts investigated the effects of the ATP-sponsored project on controlling dimensional variation in manufacturing (the "2mm project"). They looked first at the firm level to determine the technological changes that resulted from the project; the role played by the ATP; and the direct impacts on automobile production and maintenance costs. They then used macroeconomic interindustry modeling to project preliminary impacts on the national economy of adoption of the technology by the automobile industry. A challenge was to estimate the impacts based on preliminary and partial information characterizing industry experience. Some potential effects of the ATP-sponsored project were considered too uncertain at this early stage to attempt quantification and were omitted from the analysis. The results of the macroeconomic analysis provide a very preliminary projection of national economic impacts of this ATP-sponsored project.

Introduction

One of the early research joint-venture projects that was awarded funding by the Advanced Technology Program (ATP) was the "Development of Advanced Technologies and Systems for Controlling Dimensional Variation In Automobile Body Manufacturing" ("The 2mm Project"). The ATP award was made in 1991. The research began in September of 1992, and was completed in January of 1996. A total of $4.860 million in funding was committed by ATP, and an additional $9.007 million in funding was committed by the joint venture. The joint venture was comprised of: (1) a group of small- and medium-sized companies that supply assembly line equipment and consulting engineering services to automobile manufacturers and together form the Auto Body Consortium (ABC), consisting at the start of the project of eight members: APX International; ASC, Incorporated; Classic Design, Inc.; Detroit Center Tool, Inc.; ISI Automation Products Group; Modern Engineering; Perceptron, Inc.; and Progressive Tool & Industries Company (PICO); (2) the University of Michigan; (3) Chrysler Motors Corporation, General Motors Corporation (GM); and (4) Wayne State University as a subcontractor.

The 2mm Project developed technologies to control dimensional variation in automobile bodies during assembly. At an "ideal" automobile assembly plant, the sizes of openings, surfaces, parts and subassemblies would be identical on each assembled automobile body. In a real assembly plant, these sizes differ from automobile body to automobile body. These differences in sizes are referred to as dimensional variation. In addition to their application in automobile assembly, the technologies and processes that were developed as part of the 2mm Project have potential application in other industries that manufacture products which require the automated assembly of metal parts such as the appliance and metal furniture industries.

This paper summarizes the results of a study of the 2mm Project carried out by CONSAD Research Corporation under contract to the National Institute of Standards and Technology. First, the project is described as well as the problem it addressed. Then the role played by ATP is assessed. Results of early implementation of project technologies are used to estimate longer-term impacts.

Project Goals

The three stated goals of the 2mm Project were: (1) to achieve no more than a 2.0 mm variation for body-in-white (BIW) build, (2) to advance the understanding of the physical properties of sheet metal and the assembly of sheet metal parts, and (3) to enable the companies to perform the improvements on their own. The BIW is composed of the underbody, side frames, roof, shelves and backpanel. The door, hood, and deck-lid panels are installed into the openings of the assembled BIW. Later, after painting, the windshield and backlight are installed into the appropriate openings. If the BIW openings, panels, or other subassemblies vary significantly from their specified dimensional values, the assembly process can become more complicated and time-consuming than ordinary. In some cases, a BIW may require custom manual work to allow the parts to be assembled properly. In addition, the overall fit and finish of the completed automobile may be compromised if the dimensional variation is large. If the dimensional variation of a BIW is so large that it cannot be assembled properly,

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it may be removed from the assembly line and discarded.

Although some dimensional variation will always occur during automobile assembly, a goal of the automobile manufacturers is to design an assembly line system that accounts for the intrinsic variation in parts, subassemblies, and materials in a way that minimizes the total dimensional variation of the finished automobile body. The 2mm Project addressed the subject with expertise and experience from both industry and academia. The goal of the 2mm Project was to reduce the standard measure of total dimensional variation for assembly plants that adopt the project's technologies to 2.0 mm or below.

Automobiles produced by Japanese companies are generally perceived by the public to have higher quality than American cars. A report by J.D. Powers placed eight automobile models produced by Japanese manufacturers among the ten best automobiles ranked in terms of initial quality and customer satisfaction (Power and Associates 1995). Most Japanese manufacturers currently operate their U.S. and foreign assembly plants at or below 2.0 mm of total dimensional variation. Automobile industry experts believe that the U.S. market share of U.S.-made automobiles would increase if their perceived quality were to match or exceed that of Japanese cars. The 2mm joint-venture project was the response of U.S. manufacturers and suppliers to develop a coordinated and feasible approach in conjunction with assembly plant workers to solve the dimensional control problem.

Research Tasks

The 2mm Project research tasks were grouped into four program areas. These areas were dimensional measurement technology, process control methodology, technology base for future body assembly systems, and technology transfer programs. The research tasks were conducted concurrently. Considerable communication of results occurred among the researchers performing the various tasks. Each task contained at least one representative from industry who led the effort, and at least one university faculty member. Other industry engineers and graduate students were involved in the research being performed. The research was performed at university laboratories, development occurred at facilities of the assembly line producers, and data were collected and results were implemented at the assembly plants. An overview of the four program areas, the research tasks, and the organizations involved in each task appears in Figure 1.

The Role of ATP in the 2mm Project Joint Venture

It appears unlikely that (1) this complex joint venture would have been formed and (2) funding for the research project would have been coordinated without direct administrative and financial involvement by the federal government. There are several reasons.

One reason is that the problem addressed by the 2mm project was a systems problem, requiring a high degree of coordination among a number of quite different organizations. The problem at issue could not be solved by these individual organizations acting alone, even if they strongly wished to solve the problem and were willing each to undertake a research task in their respective areas of expertise. Forming large, complex research joint ventures to address a systems problem is, however, a daunting effort. Many obstacles must be overcome to organize and carry out a multitask, interdisciplinary, integrated research effort across multiple organizations with differing missions, structures, and cultures. The ATP provided the impetus for the companies to overcome the coordination barriers and to come together to organize the research joint venture needed for the systems approach to solving the problem.

Another reason that ATP's role was likely critical is that as a direct result of the long history of stringent antitrust enforcement in the automobile industry, engineers employed by any U.S. automobile manufacturer are wary about cooperating or even communicating with their counterparts in the other domestic automobile companies. In this distrustful environment, explicit involvement by the federal government may be essential to securing the participation of domestic automobile manufacturers in any collaborative research effort, particularly in complex, multitask, multicompany efforts.

An additional factor that made ATP's role critical is that the companies that supply assembly line equipment and design services to automobile manufacturers are, in general, small- and medium-sized companies with limited access to financial capital. They typically do not have research budgets that are large enough that they can independently fund the types of tasks that were conducted in the 2mm Project, and automobile manufacturers are generally reluctant to fund research projects performed by their suppliers. Project provisions for sharing and disseminating research results further encouraged the members to cooperate in the formation of the joint venture.

Yet another major factor underlying ATP's role was that the risks were not shared equally by the different members of the joint venture. The primary bearers of the risk of incomplete success on the individual tasks were the specific assembly line producers that were directly involved in the tasks. To induce their participation in the 2mm Project, partial subsidization of their research activities was necessary to compensate them for bearing disproportionate risk. ATP's financial participation in the project helped members bring in university participation, decreased the financial outlay made by these companies, and, hence, the net risk that was borne by individual members of the joint venture.

Figure 1. Summary of tasks in the 2mm project

Program Area	Stamping (Die)	Tooling	Assembly (BIW: Body in White)
Dimensional Measurement Technology	Task 3: Measurement, Modeling, and Real-Time Numerically Controlled (NC) Path Generation for Free Form Surfaces Participants: f M	Task 2: Visibility Analysis and Sequencing Simulation for Tooling Certification Participants: d h M	Task 1: Computer Aided Design and Automated Setup for In-Line Optical Coordinate Measuring Machines (OCMM) Participants: g M
Process Control Methodology	Task 4: On-Site Measurement and Process Monitoring for Stamping Participants: C M	Task 5: Information Feedback for Tooling and Process Design Participants: c1 h C M	Task 6: Process Navigators for Automobile Body Assembly Participants: c M
Body Assembly Technology		Task 8: Optimal Non-Rigid Sheet Metal Part Holding Participants: a M	Task 7: Variability Characterization and Tolerance Budget Analysis for Body Manufacturing Participants: C2 G M
		Task 9: Robust Design of Work-Holding Fixtures Participants: a1 e M	Task 10: Optimization in Multiple Panel Fitting Participants: b M
Technology Transfer			Task 11: Technology Transfer Participants: a C G W

Key to Participants

Auto Body Consortium:
- a APX International
- b ASC Incorporated
- c Classic Design, Inc.
- d Detroit Center Tool (DCT)
- e ISI Automation Products Group
- f Modern Engineering
- g Perceptron
- h Progressive Tool & Industries, Inc. (PICO)

Auto Makers:
- C Chrysler Motors Corporation
- G General Motors Corporation

Universities:
- M University of Michigan
- W Wayne State University

Implementation of 2mm Project Results by Joint Venture Members

Portions of the technologies and methodologies developed under the 2mm Project already had been transferred into operation at five motor vehicle assembly plants at the time of the case study: namely, Chrysler's Jefferson North assembly plant in Michigan; GM's Cadillac assembly plant at Hamtramck, Michigan; and GM's truck assembly plants at Shreveport, Louisiana; Moraine, Ohio; and Linden, New Jersey. Each of them was reported to have realized or exceeded the 2.0 mm goal. Since the study was conducted, a number of additional motor vehicle assembly plants have adopted the technology. Adoption by other industries is possible in the future but had not yet occurred at the time this paper was prepared.

Estimating the Economic Impacts of the 2mm Project

Initial estimates of economic impacts were made based on expert judgments of the expected future changes in costs and final demand that will result from adoption in automobile assembly plants. These judgments were obtained by CONSAD researchers from manufacturing engineers involved with the 2mm Project's research tasks, from industry and trade experts, from market analysts, and from economists with experience in the automobile and discrete manufacturing industries. The individual sources of information and judgments and information from individual plants and firms adopting the technologies are not cited because of the proprietary and confidential nature of the data. Other factors that could affect cost or demand are assumed to have remained constant.

Separate estimates are developed for the economic impacts of cost reductions resulting from productivity improvements and the economic impacts of demand increases. Different approaches were taken because it was CONSAD's view that attempts to estimate within the context of the macroeconomic model the effects of decreases in expected costs of the magnitude projected for the automobile industry, although sizable, would be infeasible. This is because the changes are likely too small in relation to total U.S. economic activity to have a reasonable expectation of being isolated and hence measured. In contrast, it was CONSAD's view that it *was* feasible within the scope and budget of the project to allow assessment of the project's quality improvement impacts in relation to total U.S. economic activity.

Estimated economic impacts of the expected reduction in production and maintenance costs are measured in terms of the total savings that might be realized by the automobile manufacturers. The cost reductions comprise substantial cost savings for the manufacturers, some unestimated portion of which may be shared with customers. The cost savings provide manufacturers with increased flexibility in applying pricing strategies that influence their market shares and profits. Equivalently, the cost decreases provide the automobile manufacturer with the option of adding more features to cars without increasing price. Allocating the cost savings between producer and consumer was not attempted.

The estimated economic impacts of the increases in market demand that are expected to be stimulated by improvements in product quality are measured in terms of the changes in total industry output and total private employment that are projected to result from those demand increases, other factors being constant. A macroeconomic model is used to estimate the economic impacts from increased market demand.

Implementation of the technologies developed by the 2mm Project will also substantially decrease the time required to launch the assembly of new automobile models. Industry experts assert that the reduction in launch times will generate sizable increases in sales for automobile manufacturers' popular new models. The available information was insufficient, however, for reliable estimation of the magnitude of the dollar sales increases, and this effect was omitted from dollar estimates.

Because the technologies developed by the 2mm Project are new, at the time of the study their impacts on industrial production and economic activity were not yet revealed in the extant empirical data on industrial performance. Therefore, to obtain realistic estimates of the likely magnitudes of any of the impacts, judgments about the anticipated consequences of applying the technologies had to be elicited from two groups of experts.

First, experts knowledgeable about the substance of the technologies were interviewed to obtain their judgments about how practical application of the technologies would affect the production processes (e.g., the utilization rates of specific inputs and the resulting production costs) and the quality of products in firms that adopt the technologies. The experts who were interviewed in this regard consisted primarily of university researchers and manufacturing engineers who were directly involved in research tasks performed on the 2mm Project, and technicians and engineers who were involved with the initial implementation of project results at the first-adopting five automobile assembly plants.

Second, experts knowledgeable about the industries and markets in which the technologies would likely be used were interviewed to obtain their judgments about the expected extent and rate of adoption of the technologies in those industries and markets. The experts who were contacted for this purpose include industry and trade experts, market analysts, and economists who have experience relating to the motor vehicle and discrete manufacturing industries.

The plausibility of the judgments provided by the two groups of experts was then evaluated by examining the coherence among the judgments provided by the various experts in each group. In addition, to the degree possible, the judgments were compared to the available empirical data on the outcomes of the initial applications of the technologies in actual industrial situations (i.e., in motor vehicle assembly plants where the technologies had been implemented), and to published evidence on the outcomes of applying similar technologies in comparable circumstances.

The macroeconomic interindustry model that was used in the study to estimate the impacts on the U.S. economy of increased demand from quality improvements was the Regional Economic Models, Inc., (REMI) Economic and Demographic Forecasting and Simulation 53-Sector (EDFS-53) Model of the national economy (for further description of the REMI model, see Treyz 1993). The model contains numerous structural equations that describe: production and output; population and the supply of labor; demands for labor and capital (including residen-

tial structures, nonresidential structures, and equipment); and wages, prices and profits. Interindustry transactions are represented by an input-output structure based on the input-output tables compiled by the Bureau of Economic Analysis (BEA). Equations representing behavioral relationships based on economic theory endogenously determine feedbacks on final demands among different industries in the economy. The model also characterizes substitution among inputs in response to changes in their relative costs, and wage adjustments in response to changes in labor market conditions. The version of REMI model that was used in the study forecasts economic activity for 53 economic sectors (including 49 private nonfarm industries, three government sectors, and the farm sector) and the aggregate national economy.

Estimated Benefits of Automotive Production Cost Savings

Engineers at GM's truck assembly plant in Linden, New Jersey, and 2mm Project researchers involved with the technology transfer at Chrysler's Jefferson North assembly plant estimate that net production costs—that is, production costs per car less the costs per car of implementing the 2mm technology—at those facilities have been reduced by approximately $10 to $25 per vehicle as a direct consequence of implementing results from the 2mm Project. The production cost savings are expected to vary at each assembly plant according to the current level of total BIW dimensional variation. The savings represent approximately one-sixth of one percent of the total production costs for an "average" automobile produced in the U.S. The reduction in production costs begins once the key technological components are in place and the automobile manufacturers' manufacturing engineers and line operators have adopted the 2mm Project's methodology. The production cost savings result from improved labor productivity and reduced waste during the assembly process.

The price of automobiles is highly inelastic with respect to changes in production costs. The automobile industry consists of a relatively small number of firms that produce highly differentiated products. When devising pricing strategies, automobile manufacturers take into account the anticipated responses of their competitors (Fellner 1972). They also use short-term pricing tactics that include factory rebates and temporary product sales to compete for customers based on price. It is, therefore, unlikely that the projected decrease in production costs will directly stimulate a discernible reduction in the price of automobiles. However, since the market for automobiles is very competitive, the results of the 2mm Project will allow the automobile manufacturers who adopt the dimensional variation technologies to be more flexible in responding to changes in the market for automobiles.

Industry experts estimated that, over the next five years, all of GM's and Chrysler's assembly plants would adopt the results of the 2mm Project. Upon full adoption, an estimated $10 to $25 net savings realized on each of the approximately 6.5 million cars and light trucks produced annually by GM and Chrysler will amount to an overall net savings of approximately $65 million to $160 million annually. To the degree that the price of automobiles does not decline in response to the projected decrease in production costs, the automobile manufacturers will realize increased profits.

Estimated Benefits of Automotive Maintenance Cost Savings

While an automobile is under warranty, the automobile manufacturer compensates the automobile dealer who performs repairs on the automobile. According to representatives of GM and Chrysler, approximately $500 of the retail price of a new automobile, on average, is associated with the expected amount of maintenance work that will need to be performed while the automobile is covered by the manufacturer's warranty. Only a portion of this maintenance work is necessitated by the quality of the BIW; the rest involves repairs to other components, such as the powertrain, the electrical and computer systems, and interior and exterior trim. Maintenance costs vary among automobile models. No data currently are available to characterize how much maintenance work will be avoided in the future due to the reduction in dimensional variation of BIWs that will result from the implementation of 2mm Project results. The magnitude of the cost savings associated with avoiding future maintenance work is clearly lower than the hypothetical limit of approximately $500 per vehicle, but is not known at this time.

Precise estimates may be possible in the future, as automobiles that are assembled using technologies developed by the 2mm Project complete their warranty period. At present, however, estimates of the reduction in maintenance costs that will be achieved for automobiles are necessarily imprecise. The average decrease is estimated to lie in the range of $50 to $100 per vehicle.

If, as industry experts anticipate, the project's results are adopted in all of GM's and Chrysler's assembly plants within five years, maintenance cost savings will ultimately be realized on all of the approximately 6.5 million cars and light trucks produced in those plants annually. Thus, over the useful lives of the vehicles produced in those assembly plants during a year, total savings in maintenance costs ranging from $325 million to $650 million are estimated as a result of the 2mm Project. If sales of vehicles assembled in the plants remain relatively stable over time, this level of total cost savings becomes the estimated annual cost savings, on average, over time. Much of the savings will accrue to the automobile manufacturers during the vehicles' warranty periods; the balance will accrue to the vehicles' owners thereafter.

Estimated Macroeconomic Impacts of Automobile Quality Improvements

The largest impact of the 2mm Project anticipated by the joint venture members is an increase in market share for U.S.-made automobiles due to improved product quality. Currently, industry experts believe that, on balance, the styling, performance, and price of automobiles manufactured by U.S. companies are comparable to those of automobiles produced by foreign companies. However, the quality of American automobiles, measured through customer surveys (e.g., Powers and Associates 1995), is perceived to be less than that of foreign-made automobiles.

Figures 2 and 3 present estimates of the increases in total industrial output and total private employment in the U.S. that are expected to be stimulated by the quality improvements achieved by U.S. automobile manufacturers through their adoption of "2mm" technologies. Although substantial economic impacts are associated with the direct effects of the 2mm Project on the automobile manufacturers, even larger estimated impacts are expected to be realized by the entire U.S. economy because of the larger indirect effect that a change in sales in the automobile industry will have on many other business sectors. These economic impacts were estimated in simulations performed using the national economic model. Underlying the estimates are judgments by joint venture members and other automobile industry experts about the increase in market share that will be elicited by the improvements in automobile quality.

Only the lower-bound scenario has been simulated. The scenario analysis assumes that the total size of the market for automobiles will not be affected by the project, but that the percentage of total U.S. automobile sales captured by GM and Chrysler will be higher at the expense of foreign-made automobiles. The lower-bound scenario assumes that the combined market share of GM and Chrysler will increase (relative to the baseline) by 1.0 percent. The value represents the smallest estimate obtained by CONSAD from industry experts.

Projections of the impact of the expected change in product quality on sales of U.S. produced automobiles were developed by estimating the increase in sales of domestically produced automobiles that would result from an increase in market share for GM and Chrysler. For a given level of increase in market share for GM and Chrysler, the change in sales of domestically produced automobiles is estimated to be equal to the increase in market share for GM and Chrysler multiplied by the ratio of the current market share for imported automobiles to the total U.S. market share for automobiles NOT produced by GM or Chrysler. This approach is based on the assumption that increased market share for GM and Chrysler that displaces the sales of imported automobiles will result in an increase in economic activity in the U.S. In contrast, it is assumed that increased market share for GM and Chrysler that displaces domestically produced automobiles will have no net effect on economic activity in the U.S. It is further assumed that Ford's market share will remain constant during the period of analysis. This assumption seems conservative given that all the U.S. assemblers share the same supplier base.

The projected increase in market share was introduced as an input into the REMI model, and the corresponding future changes in industrial output and private sector employment were estimated by the model. Estimates are presented for the years 1995 to 2000. Impact estimates for years after 2000 are not reported because of the increasing uncertainty in predicting developments in automobile production technology farther into the future.

Figure 2 shows that the quality improvements of the 2mm technologies in the automobile industry are projected to stimulate an increase in total industrial output in the year 2000 of more than $3 billion. The cumulative output increase between 1995 and 2000 is projected in excess of $8 billion, based on the lower end of the range of assumed market share response.

The REMI model was also used to project how the quality gains might affect employment. As shown in Figure 3, quality improvements in automobiles may stimulate thousands of new jobs across the economy, taking into account interindustry effects and assuming that the economy is able to absorb new jobs. The REMI estimates are based on the assumption of a Keynesian economic response to the modeled changes in product quality which permits an increase in employment to occur without the assumption of an immediate constricting action in monetary policy to offset the employment gains. Of course, to the extent that the economy is operating at full employment with strong wage pressures over this period, there would be a tendency for newly created jobs to be filled by workers moving from existing jobs, a tightening in monetary policy, and less opportunity for a net gain in total national employment.

Limitations

The methodology used for this case-study analysis relied on expert judgments and limited data to characterize and estimate the economic impacts of the technologies developed by the 2mm Project, and implemented by automobile manufacturers. The use of experts was necessary because of the lack of extant empirical data describing: the direct impacts of the 2mm Project technologies on the production processes across different assembly plants (estimates were based on the experience of several plants); the rate of adoption of the technologies by automobile manufacturers; and the magnitude of impact of the resulting increase in product quality on the sales of automobiles. These data had to be estimated because the new technologies developed by the 2mm Project are in the early stages of adoption at automobile assembly plants in the U.S.

The use of judgments from experts who are familiar with the technologies developed as part of the 2mm Project

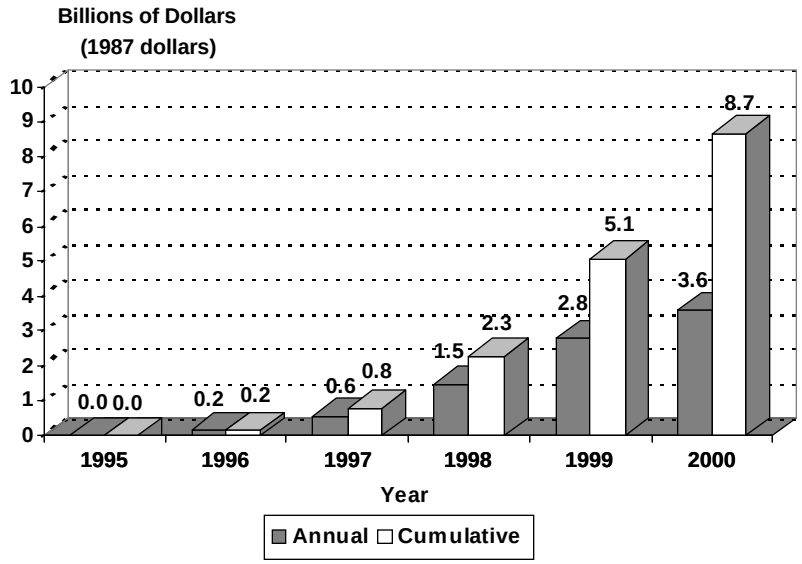

Figure 2. Estimated increase in total industrial output due to the adoption of 2mm program results by automobile industry based on assumed 1.0 percent increase in market share

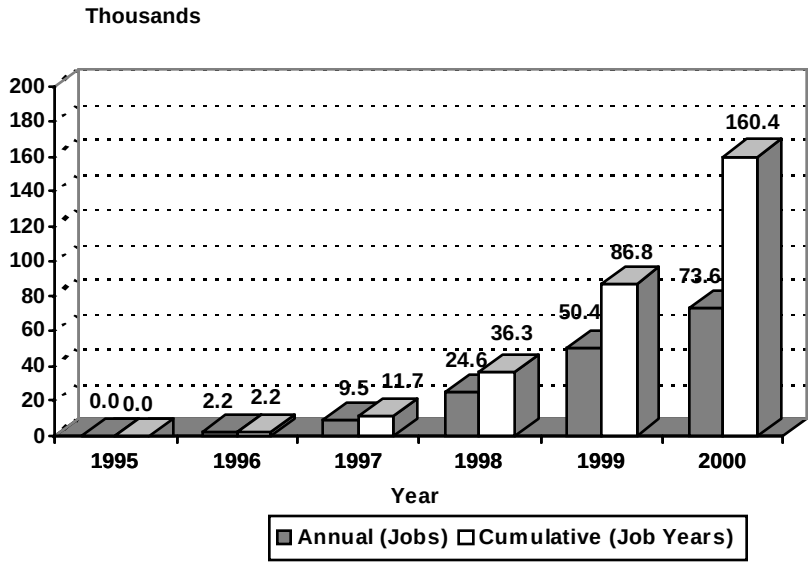

Figure 3. Estimated increase in total private employment due to the adoption of 2mm program results by automobile industry based on assumed 1.0 percent increase in market share

may result in biases but the existence, type, and size of possible bias cannot be determined at this time. Economic projections, in general, involve estimates of how individuals and firms will behave in the future under circumstances that may not be well-characterized by existing available data. Thus, all such projections rely on expert judgment to some extent. When more facilities have adopted the technologies, then additional data can be collected and compared with the expert judgment to gauge the accuracy of the estimates used in this analysis.

An additional obstacle to performing case studies such as this is the need for data which is sometimes viewed as proprietary by the companies. Since the existing data and information describing the specific impacts of the technologies developed as part of the 2mm Project pertain to specific company facilities that have already adopted part of the technologies, these data were considered proprietary in nature, to be treated as commercial secrets. Thus, the full details of the data used in estimating cost savings and market share have not been documented here, but have been used to guide the estimates and choice of parameter values used in the analysis. This situation is not uncommon in performing industrial case studies, and will probably not be addressed differently in other case study analyses since it is the nature of firms in competition to maintain certain information as proprietary.

A further limitation was that not all of the observed effects of the technology on the automobile industry could be modeled using the REMI model. For this case-study analysis, although the estimated auto production cost changes associated with the adoption of the technologies are sizable, these costs are relatively small compared to the total production costs of the automobile manufacturing industry. The analytic content of the 53-sector REMI model was not detailed enough to allow projecting of the total impact of the production cost savings on the entire economy. But production and maintenance cost savings were modeled and estimated outside the REMI model. Finally potential impacts from adoption of the technologies by other manufacturing sectors were omitted. At this early stage, there is simply too little information on the likely adoption of the technologies by other manufacturing sectors and the resulting impacts on production costs, product quality, and sales in those other sectors.

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